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Operation TEAPOT

NEVADA TEST SITE

February – May 1955

Project 39.3

THERMAL RADIATION MEASUREMENT

Issuance Date: May 13, 1957

FC

CIVIL EFFECTS TEST GROUP

Report to the Test Director

THERMAL RADIATION MEASUREMENT

By

Staff of Edgerton, Germeshausen & Grier, Inc.

Approved by: ROBERT L. CORSBIE
Director, Program 39
Director, Civil Effects Test Group

Edgerton, Germeshausen & Grier, Inc.
Boston, Massachusetts
Las Vegas, Nevada
October 1956

ABSTRACT

The purpose of Project 39.3 was to measure the thermal flux per unit area at a series of specified distances from a nuclear detonation. The instrumentation chosen was an Eppley thermopile indicating on a strip-chart paper recorder.

Two stations failed to yield results because of power failures and blast damage. Results were obtained at 5500, 6800, and 10,500 ft. These results follow the inverse-square-law fall-off, within the limits of reasonable experimental error.

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CHAPTER 1

OBJECTIVE

Project 39.3, Thermal Radiation Measurement, was organized to serve as a support group for Project 31.5, Thermal Ignition and Response of Materials. Its objective was to measure the thermal flux per unit area at a series of specified distances and at a specified azimuth from a nuclear detonation. The location for the measurement stations corresponded with those chosen by Project 31.5 for their samples.

CHAPTER 2

INSTRUMENTATION

Ten thermopiles, with their associated recorders, were set up at five distances from the detonation. Five of these yielded thermal pulses which appeared normal and suitable for analysis. The five traces were obtained at the three outermost stations, A and B at 10,500 ft, A and B at 6800 ft, and A at 5500 ft. The thermopiles, each with a different filter, were placed about 3 ft above, and parallel to, the ground, facing the source, which was detonated on a tower. Table 2.1 summarizes the thermopile instrumentation; Fig. 2.1 shows the electrical instrumentation of each station.

Table 2.1 — THERMOPILE INSTRUMENTATION

Distance, ft	Unit	Attenuating filter	Transmission, %	Remarks
3,750	A	0.041-in. aperture		Power failure
3,750	B	0.031-in. aperture and evaporated metal on glass		Pen goes off scale
4,700	A	0.052-in. aperture		Mechanical damage
4,700	B	0.041-in. aperture		No pen deflection
5,500	A	0.060-in. aperture	See Fig. 2.3	Record
5,500	B	0.041-in. aperture		Trace does not return to zero
6,800	A	0.086-in. aperture	See Fig. 2.3	Record
6,800	B	0.054-in. aperture	See Fig. 2.3	Record, off scale
10,500	A	Evaporated metal on glass	6.9	Record, off scale
10,500	B	Evaporated metal on glass	4.7	Record, off scale

The recorders were calibrated to give a full-scale deflection for 1-mv input, as illustrated in Fig. 2.2.

To provide the chart time scale, a time interval of 1 min was measured with a stop watch and recorded for each instrument.

The filters on the operating units at 5500 and 6800 ft were metal disks with small holes drilled through the centers. The transmission of these filters was calibrated in the laboratory by the setup shown in Fig. 2.4. The flux was measured without any filter, and percentage values of that flux were calculated as the thermopile with the filter was rotated in 2-deg steps from normal until no flux was recorded. Curves for each filter were drawn.

The filters at 10,500 ft were thin metal films deposited on glass and protected by a cover glass. The percentage of transmission was measured normal to the source only since there was no appreciable decrease in transmission as the bare thermopile was rotated well beyond the angle at which these thermopiles would see the source. A certificate of sensitivity calibration accompanied each thermopile.

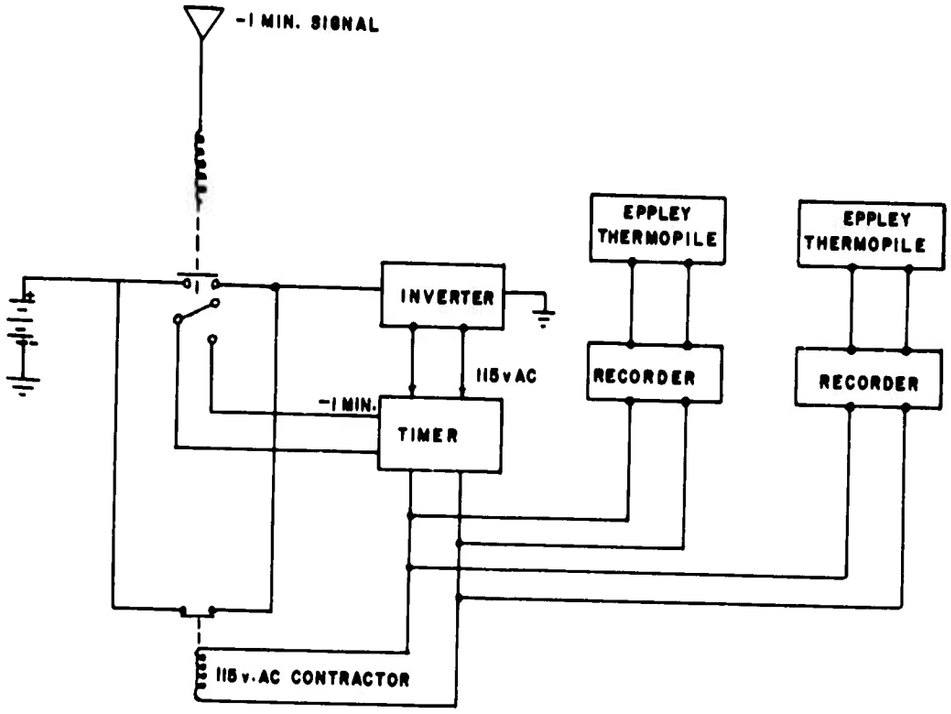

Fig. 2.1—Schematic diagram of thermal-flux recorder.

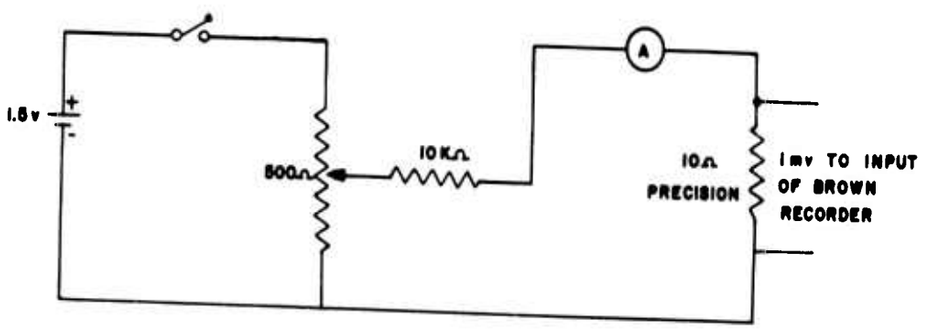

Fig. 2.2—Recorder calibration circuit.

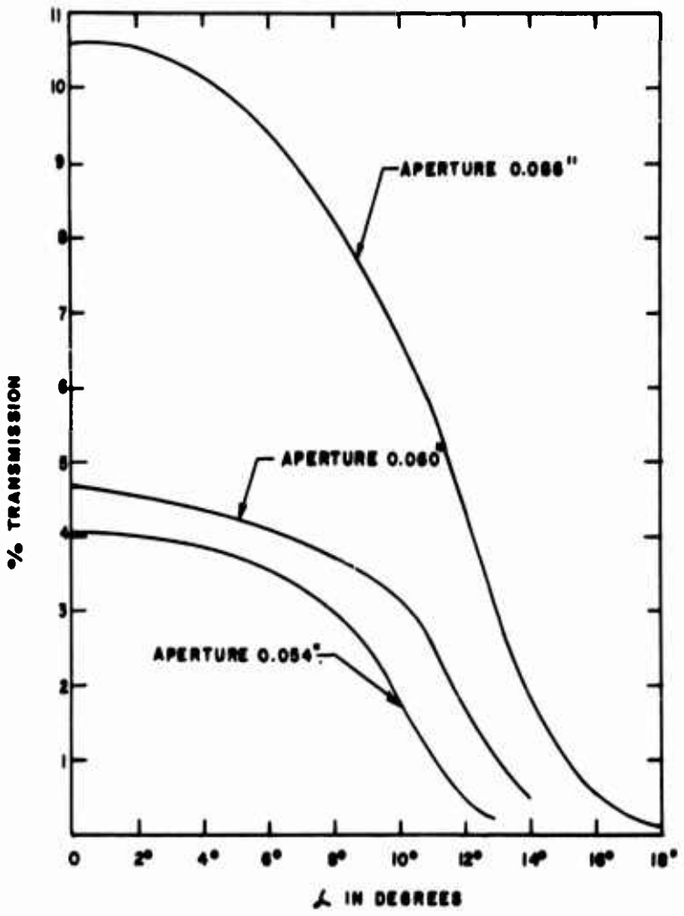

Fig. 2.3—Transmission as a function of thermopile orientation.

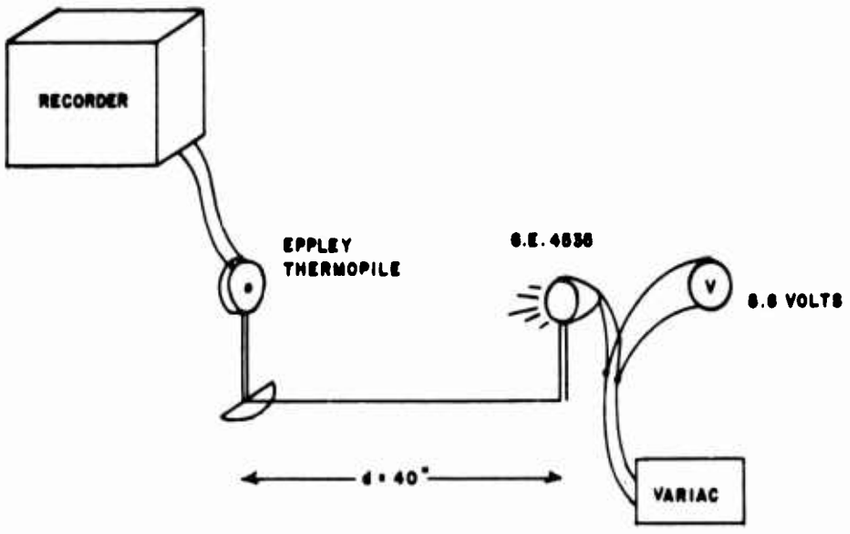

Fig. 2.4—Schematic diagram of filter-transmission calibration.

CHAPTER 3

ANALYSIS

Investigation of the geometry of the field experiment indicates that some correction for the shape of the source and the angle at which the thermopile "looked" at the source is necessary. The source was approximately elliptically shaped and was located near the edge of the round field of view of the receiver. As shown in Fig. 3.1, the source did not touch the center of the field of view.

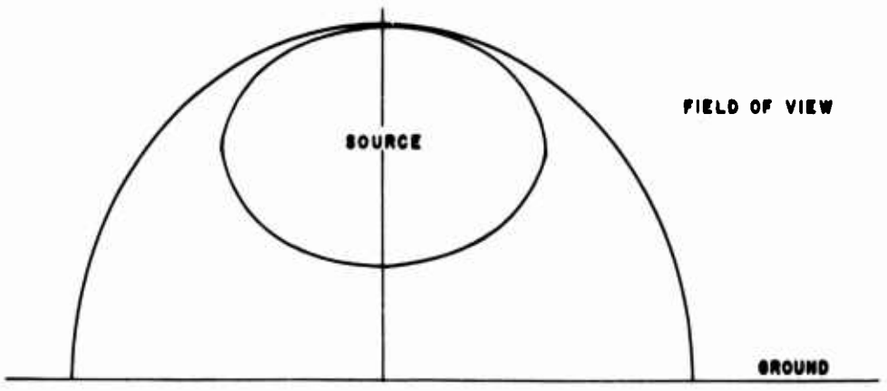

Fig. 3.1—Source and field-of-view geometry.

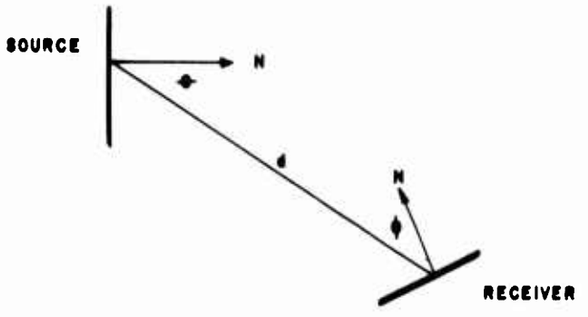

Fig. 3.2—Flux at the receiver.

The flux at the receiver for a general case is illustrated in Fig. 3.2 and may be stated as follows:

$$F = Bab \cos \theta \cos \phi / d^2$$

where a = the area of the source
b = the area of the receiver
B = the luminance of the source

The flux at the receiver in the case illustrated in Fig. 3.3 is

$$F = Bab \cos^2 \alpha / d^2$$

or

$$F = Bab \cos^4 \alpha / D^2$$

where $d = D/\cos \alpha$.

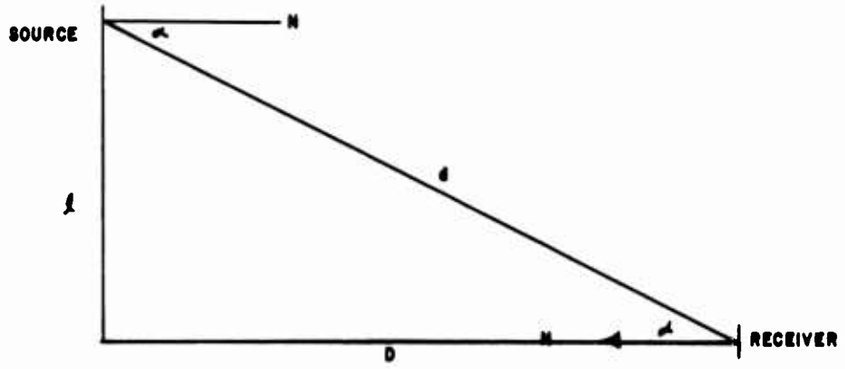

Fig. 3.3—Flux geometry.

The area of the source may be considered the sum of the portions of the annuli, as shown in Fig. 3.4. (It is necessary to define area in this manner in order to correct for the transmission of each filter, which varies rapidly with α.) The area of each annulus is $A = 2\theta \ell \, d\ell$. From the following expression ℓ as a function of β may be found

$$\ell^2 = H^2 + x^2 + y^2 - 2H\sqrt{x^2 + y^2} \cos \beta$$

θ is then found from

$$\sin \theta = \sin \beta \cdot \frac{\sqrt{x^2 + y^2}}{\ell}$$

θ plotted as a function of ℓ will give a corresponding θ for each ℓ and the area may be found from

$$A = 2\theta \ell \, d\ell$$

For each ℓ there exists a corresponding α which may be plotted as a function of area. The theoretical flux due to the source is then

$$F = \frac{Bb}{d^2} \sum a \cos^4 \alpha$$

where Bb/d^2 is a constant.

The flux from the source, however, is attenuated by a filter. The experimentally received flux will be

$$F = \frac{Bb}{d^2} \sum a \cos^4 \alpha r$$

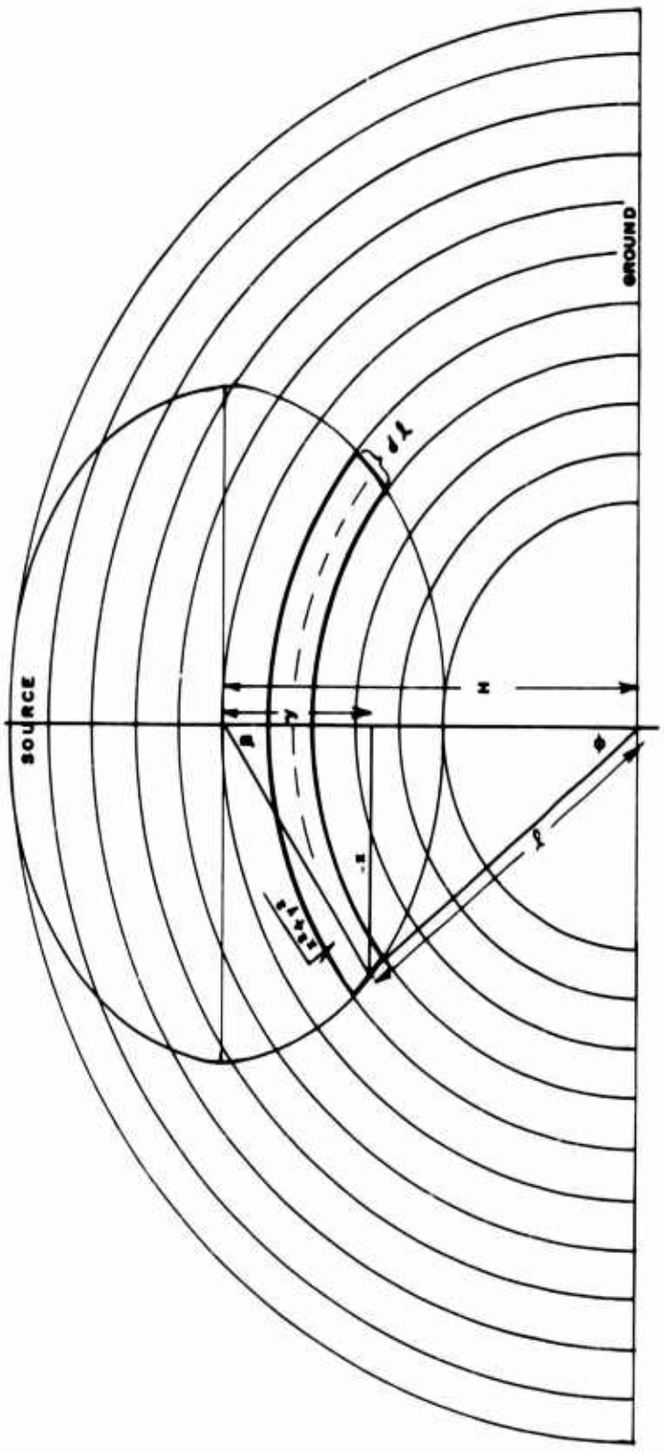

Fig. 3.4—Effective source area.

The unfiltered flux divided by the attenuated flux gives the factor by which the experimental flux value must be raised.

The experimental flux value is obtained from the area of the chart recording. The seconds per linear inch and the millivolts per linear inch were determined for each trace from the recorder calibration giving millivolt seconds per square inch. The thermopile sensitivity is rated in calories per square centimeter per millivolt second. The sensitivity multiplied by the recorder characteristics multiplied by the area under the curve, measured with a planimeter in square inches, gives the flux in calories per square centimeter received by each thermopile. This flux, increased by the factor due to the nonnormal orientation of the source and receiver and the filter attenuation, gives the actual flux received at each station.

CHAPTER 4

RESULTS

Data were obtained at only the three more distant stations. At the 3750-ft station the power failed at shock arrival. At the 4700-ft station the lines to one thermopile were cut by flying debris. Although the chart drive motor operated normally, the record from the other thermopile at this station does not show any deflection, presumably because of a faulty balance circuit in the recorder.

The records from the three distant stations are not ideal because they all have off-scale deflections at the peak. However, since the fall-off is an exponential function, the peaks can be satisfactorily extrapolated. At the 5500-ft station recorder B shows neither the peak nor the entire fall-off. At about 60 per cent of the peak, there is a power failure, and the pen ceases to trace properly.

The results of this project are shown in Table 4.1 and Fig. 4.1. The logarithm of the flux plotted against the logarithm of the distance gives very nearly a straight line with a slope of −2, indicating that the flux is inversely proportional to the square of the distance.

Table 4.1—MEASUREMENT OF THERMAL FLUX

Distance, ft	Recorder	Flux, cal/cm^2
5,500	A	10.8
6,800	A	6.8
6,800	B	10.4
10,500	A	3.0
10,500	B	3.2

The results obtained with recorder B at 6800 ft are unexplainably high. It is believed that this value is erroneous. It is believed that the straight line drawn in Fig. 4.1 represents the thermal flux as a function of distance with an accuracy of ±20 per cent.

The preliminary investigations suggested that there might be a problem due to dust masking the thermopiles, which were relatively close to the ground. This possibility has been investigated through the use of available photographic records, and it is concluded that a significant dust pall did not rise until after the thermal pulse.

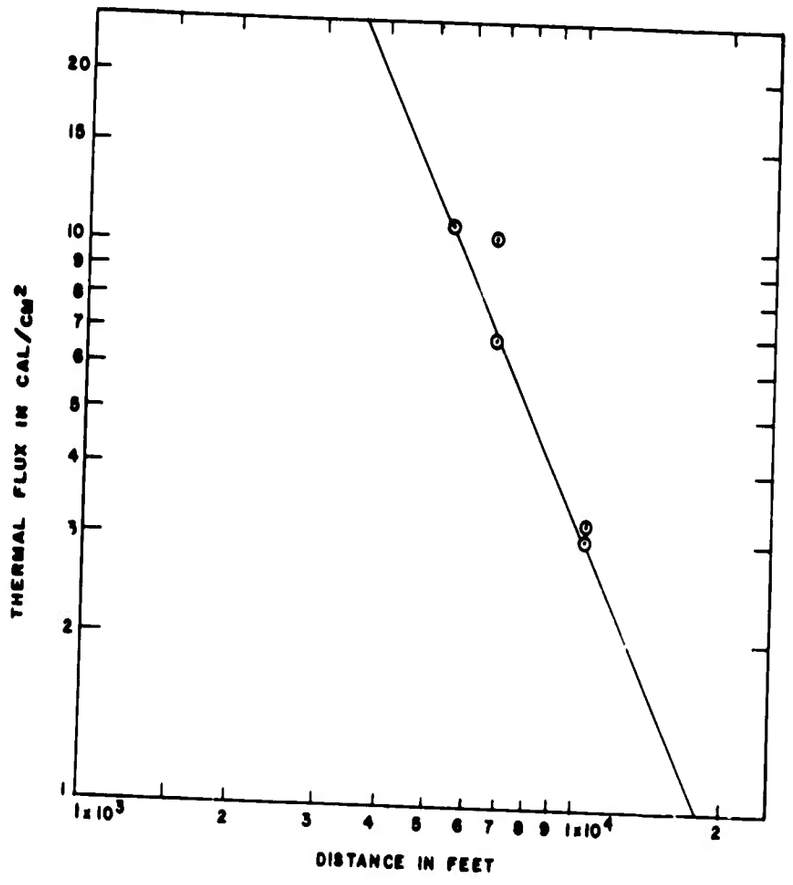

Fig. 4.1—Calories per square centimeter vs distance.

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